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# Experimental and Numerical Investigations on the Response of a Multi Tubes and Fins Heat Exchanger under Steady State Operating Conditions

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## Abstract

In this study, experimental and numerical investigations on the response a multi tubes and fins heat exchanger under steady state operating conditions have been carried out. A test setup has been developed in order to study the heat transfer and pressure drop characteristics of this heat exchanger. In accordance with the heat exchanger used for experiments, an identical geometry numerical 3D model has been created. The numerically calculated results have been validated against experimental data in terms of air outlet temperature and pressure drop measured across airside. Moreover, two novel design equations have been developed to predict the heat transfer rate and the pressure drop across the airside, after conducting a comparative numerical study on the airside performance of the multi tubes and fins heat exchanger having plain, louvre and semi-dimple vortex generator (VG).

***Keywords: Multi tubes and fins heat exchanger, Louvre fins, Semi-dimple vortex generator, CFD modelling, steady operating condition.***

## I. INTRODUCTION

Heat exchangers are used in many applications, such as in heating, ventilation and air conditioning systems (HVAC), power generation and manufacturing system. The procedure of designing and predicting the performance of a heat exchanger is important for better performance of the system under various operating conditions. Many studies have been carried out to improve the performance of heat exchangers. These studies include analysis of the use of active techniques which use external forces, such as electric field, surface vibration, as well as passive techniques which include the use of special surface geometries or fluid additives [1]. Wang et al. [2] carried out experimental investigations on 15 samples of plate fin and tube heat exchanger with different geometries. Wang et al. [3] studied the airside performance of fin and tube heat exchangers with plain fin configurations. The author concluded that the fin pitch had a strong effect on the heat transfer characteristics. Wang et al. [4] carried out an experimental comparative study of the airside performance of fin-and-tube heat exchanger having plain, louvre and semi-dimple vortex generator (VG) for various combinations of number of tubes rows and fin pitch. The results of this study indicated that the effect of a number of tubes rows on the heat transfer coefficients was small for both louvre and semi-dimple vortex generator fin geometry. The works presented above have established the effect of geometry on heat transfer and pressure drop across a heat exchanger. However, these studies are more concentrated on the fin geometry and fin pitch and so far have not explored the development of general design equations for a variety of cases. In the present study, multi tubes and fins heat exchanger with multiple row tube configurations will be investigated for different geometrical parameters under steady state operating conditions, in order to develop general equations that can be used to design heat exchangers, by using experimental and numerical computation techniques.

## II. EXPERIMENTAL PROCEDURE

### A. Experimental Setup

An experimental setup has been designed and built to perform the experiments on a multi tubes and fins heat exchanger under steady state operating conditions.

### B. Heat Exchanger Testing Unit

Figure 1 shows a schematic diagram of the heat exchanger testing unit. The testing unit was made up from galvanised sheet steel with 2 mm thickness. The test section is 650 mm long, 165 mm wide and 175 mm high. The heat exchanger used in this study is multi tubes and fins type. It consists of two rows of tubes of 9.52 mm diameter, each row contains 5 tubes, the over length of each tube is 130 mm and they are joined together with 16 mm bend. Tubes are made up from Copper with 0.26 mm thickness. The heat exchanger has 22 staggered louvre fins made up from Aluminium with 0.12 mm thickness. Fins are 44 mm wide and 125 mm high and they are identical to those used in [4]. The fins are placed 4.23mm apart from each other (6 fins per inch).

### C. Tests Procedure

The tests were performed by drawing air flow over the fins

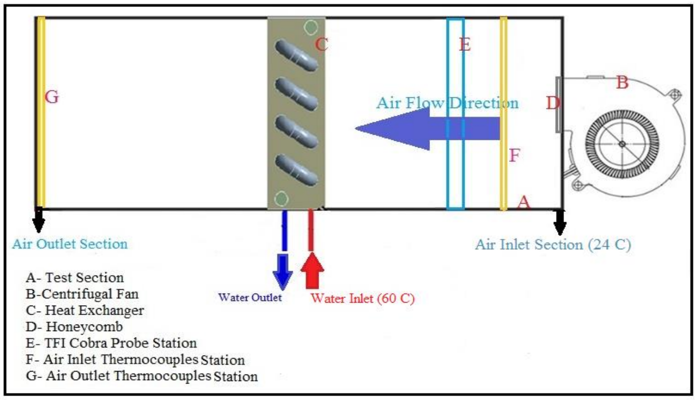


**Fig.1 Schematic of the Heat Exchanger Testing Unit**

side of the heat exchanger, while circulating hot water through the tubes of the heat exchanger. The Colburn j factor and Fanning friction factor *f* are adopted to evaluate the airside performance of the heat exchanger. The reduction method for obtaining those factors can be found from [5].

## III. NUMERICAL SIMULATION MODEL AND NUMERICAL METHODS

### A. Numerical Simulation Model

The commercial software ANSYS/FLUENT 17.0 is employed in this study to carry out the numerical simulations for a turbulent flow case. The model was built with the same geometry as in the experimental model. The governing equations of the flow and heat transfer are the mass conservation in 3D (continuity), momentum equations in 3D and energy equation in 3D. A double precision steady solver and realisable k-epsilon model and standard wall functions were adopted as settings in this study.

### B. Mesh Independence Test

In this study, a mesh independence test has been carried out with three different (5.5, 11 and 22 million mesh elements). The results of this test indicate that there is no any significant change in the results between 11 and 22 million mesh models, hence the 11 million mesh elements model has been chosen for further analysis.

### C. Data Validation

In this section, the numerically predicted results have been validated against experimental data in terms of air outlet temperatures and pressure drop across the air sides. Figure 2 depicts a comparison between the numerically predicted results and the experimental data for air outlet temperatures and airside pressure drop. From the figure it can be seen that, numerical results match very well with the experimental results. Therefore, the presented numerical model is reliable and it can be used in any further study.

## IV. RESULTS AND DISCUSSION

### A. Experiments Results

Figure 3 depicts the variations of Colburn j factor and Fanning friction factor *f* with water Reynolds number.

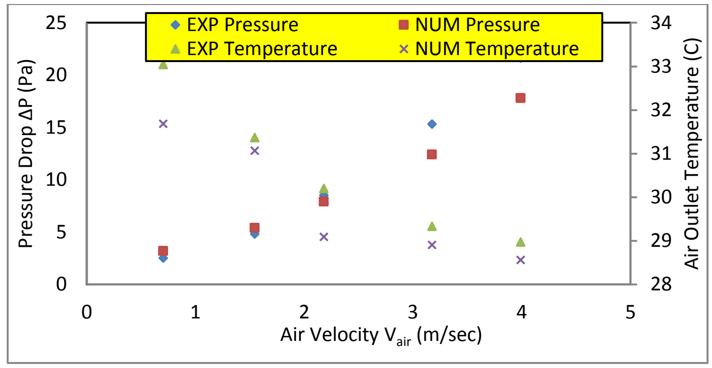


**Fig. 2 Comparison of Numerical and Experimental Results for Air Outlet Temperature and Airside Pressure Drop**

As shown in this figure, both factors tend to decrease with increasing Reynolds number. Moreover, it can be noted that at the same Reynolds number, friction factor is ten times more than Colburn factor.

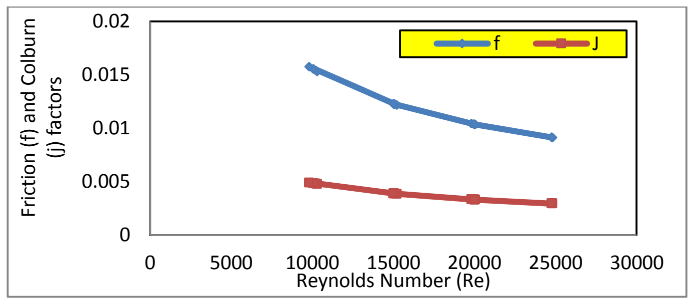


**Fig.3 Variations of Colburn j Factor and Fanning Friction Factor *f* with Water Reynolds Number**

### B. Results for the Comparative Numerical Study of the Airside Performance

In this section, a comparative numerical study of the airside performance of multi tubes and fins heat exchanger under steady state operating conditions having plain, louvre and semi-dimple vortex generator (VG) has been carried out. The comparison was made in terms of effectiveness and pressure drop across the airside. The fins used in this study are identical to those used in [4]. Fin pitch values considered in the present investigations were 1.6 and 2.0 mm. The water Reynolds number was kept constant (approximately 38,000). Figures 4 and 5 depict the variations of the effectiveness and the pressure drop across the airside with air velocity at 1.6 mm and 2.0 mm fin pitch, respectively.

Figure 4 reveals that the effectiveness for semi-dimple vortex generator fin geometry is higher than those of louvre and plain fin geometry for both fin pitch. Moreover, the effectiveness is higher at low air flow velocity for all fin types, and the values for the effectiveness of 1.6 mm fin pitch are higher than those at 2.0 mm, for all fin types. From figure 5 it can be seen that, the pressure drop across the airside is lowest for plain fin geometry than those of louvre and semi-dimple vortex generator fin geometry for both fin pitch values.

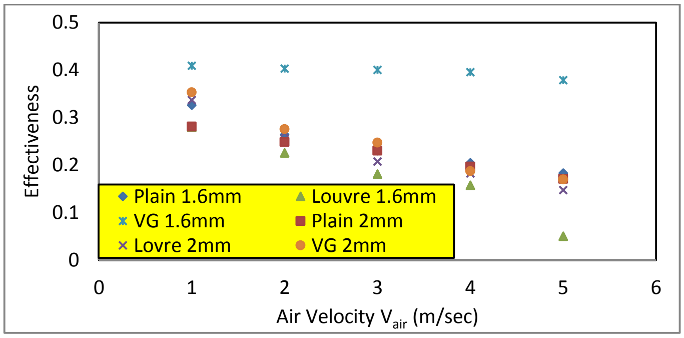


**Fig.4 Variations of the Effectiveness with Air Velocity at 1.6 mm and 2 mm Fin Pitch**

Generally, the pressure drop decreases with the increase in fin pitch. These results have a good agreement with the experimental study done by [4].

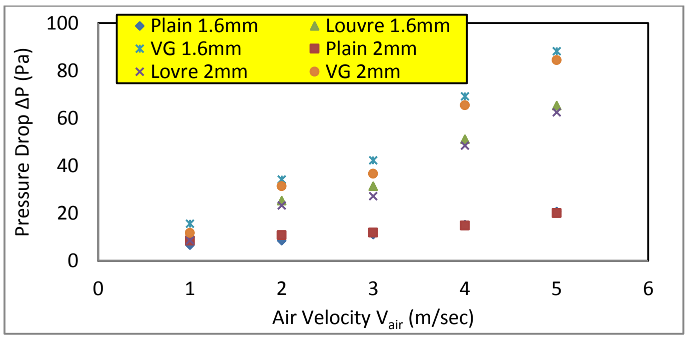


**Fig.5 Variations of the pressure drop across the airside with Air Velocity at 1.6 mm and 2 mm Fin Pitch**

Figures 6 and 7 depict the effect of velocity ratio ($V_{air}/V_{water}$) and area ratio (б), the ratio of minimum free flow area to frontal area, on the non-dimensional heat transfer parameter ($\dot{Q}_{air}/0.5\dot{m}_{air}V_{air}^2$) and on the non-dimensional pressure drop parameter ($\Delta P_{air}/0.5\rho_{air}V_{air}^2$), respectively.

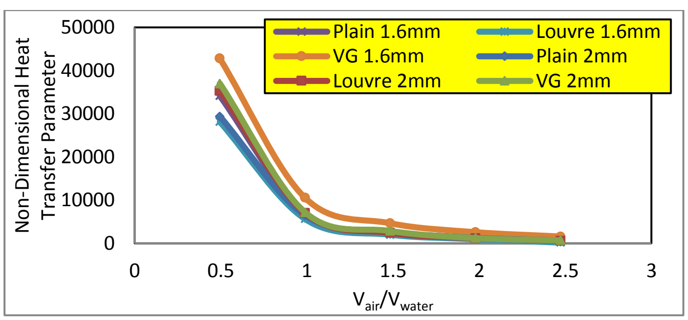


**Fig.6 Effect of Velocity Ratio and Area Ratio on the Non-Dimensional Heat Transfer Parameter**

Using multiple variable regression analysis, the presented tests results has been correlated in order to predict the heat transfer rate and the pressure drop across the airside. These novel equations are shown below.

$$\frac{\dot{Q}_{air}}{0.5\dot{m}_{air}V_{air}^2} = \frac{3.823\sigma^{0.022}}{\left(V_{air}/V_{water}\right)^{2.414}} \quad (1)$$

$$\frac{\Delta P_{air}}{0.5\rho_{air}V_{air}^2} = \frac{25.982}{\left(V_{air}/V_{water}\right)^{6.348}\sigma^{8.979}} \quad (2)$$

These equations can be used to design heat exchangers for a given heat transfer and mass rate of flow.

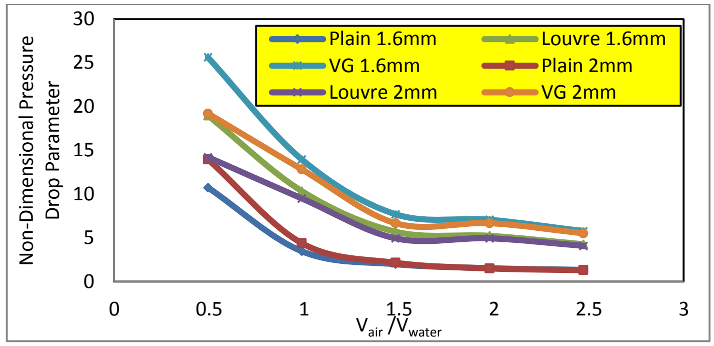


**Fig.7 Effect of Velocity Ratio and Area Ratio on the Non-Dimensional Pressure Drop Parameter**

## V. CONCLUSIONS

A comparative numerical study of the airside performance of multi tubes and fins heat exchanger under steady state operating conditions having plain, louvre and semi-dimple vortex generator (VG) has been carried out. The comparison has been done in terms of effectiveness and pressure drop across the airside. This study has been performed after a data validation between the numerically predicted results and the experimental results. The percentage differences for the validation were in acceptable range. Furthermore, the results of the comparative study have been used to develop two novel design equations for predicting the heat transfer rate and the pressure drop across the airside.

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